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Global Innovation Networks as first steps towards a Global Innovation System

Eduardo da Motta e Albuquerque
Gustavo Britto
Otávio Silva Camargo
Glenda Kruss

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CENTRO DE DESENVOLVIMENTO E PLANEJAMENTO REGIONAL

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Global innovation networks as first steps towards a Global Innovation System[*]

Eduardo da Motta e Albuquerque
Cedeplar/FACE-UFMG, Brazil.

Gustavo Britto
Cedeplar/FACE-UFMG, Brazil.

Otávio Silva Camargo
Cedeplar/FACE-UFMG, Brazil.

Glenda Kruss
HSRC, South Africa.

CEDEPLAR/FACE/UFMG
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SUMÁRIO

RESUMO

Esse artigo tem o objetivo de expandir o horizonte de análise, assim como aprofundar os estudos das interações entre universidades e empresas no contexto global. Como ponto de partida, duas linhas de pesquisa existentes na literatura são apresentadas. A primeira é a literatura sobre interações, capitaneada por Klevorick et al (1995) e Nelson (1993), e a segunda a discussão mais recente sobre Redes Globais de Inovação (GINs), proposta por Ernst (2006) e pela *The Economist Intelligence Unit* (2007). Estas vertentes possuem um problema comum: cada uma tem um ponto cego em relação à temática central da outra. A literatura sobre interação não trata de maneira apropriada a dimensão internacional, e a literatura sobre GINs não inclui plenamente a importância das universidades. O artigo propõe a solução dessas limitações través de uma combinação das duas vertentes, procurando diferentes manifestações das interações entre firmas e universidades em uma escala internacional. Ao fazer isso, o artigo propõe uma tipologia alternativa sobre as interações entre universidades e empresas.

Palavras-Chave: interações entre universidades e firmas, sistemas nacionais de inovação, redes globais de inovação.

ABSTRACT

This paper aims to broaden the horizon as well as to shed further light on the studies of interaction between firms and universities in a global context. Its starting point is thus a review of two different strands of the literature on innovation. First, the literature on interaction by Klevorick et al (1995) and Nelson (1993), and second, the more recent literature on Global Innovation Networks (GINs) by Ernst (2006) and *The Economist Intelligence Unit* (2007). These strands share a common problem: each has a blind spot in relation to the core focus of the other strand. The literature on interaction does not consider the international dimension in any depth, and the GINs literature does not integrate the university dimension adequately. This paper addresses the common weakness through a combination of the two approaches, searching for interactions between firms and universities globally. In doing so, the paper also puts forward a tentative framework on global interaction between firms and universities.

Key Words: interactions between firms and universities, national systems of innovation, global innovation networks.

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INTRODUCTION

The INGINEUS Project offers a great opportunity to students of the interaction between firms and universities to broaden their horizon and understand their subject in a global context. Previous studies - whether in the North (Klevorick et al, 1995) or in the South (Lee, 2009; Kruss, 2009; Dutrénit, 2010) - have been able to capture only part of the broad picture. Research on global innovation networks (GINs) provokes students of interaction to advance towards a real global perspective. Indeed, as international connections are more widespread and more active than is typically assumed or explicitly stated, this global view is a better starting point for a study of interaction, or even a necessary starting point, given the global nature of science and technology.

The starting point of this paper is thus a review of two different strands of the literature on innovation - first, the literature on interaction (Klevorick et al, 1995; Nelson, 1993), and second, the more recent literature on GINs (Ernst, 2006; *The Economist Intelligence Unit*, 2007). These strands share a common problem: each has a blind spot in relation to the core focus of the other strand. The literature on interaction does not consider the international dimension in any depth, and the GINs literature does not integrate the university dimension adequately.

This paper addresses the common weakness through a combination of the two approaches, searching for interactions between firms and universities globally. It includes the global dimension in the first approach and universities in the second. A critical review of the available literature in Sections 1 and 2 summarizes the strengths of each strand, and how they deal with each other's primary focus. On this basis, Section 3 introduces a tentative framework on global interaction between firms and universities.

I. GLOBAL INNOVATION NETWORKS: A REVIEW OF THE LITERATURE

The intellectual trajectory of Dieter Ernest's work has been seminal in investigating the international nature of production and innovation, with a special focus on the rising East Asia economies. Ernst proposed the concept of *global innovation networks* (GINs) after investigations of global production networks, knowledge flows and the changing geography of innovation systems (Ernst, 2002; Ernst & Kim, 2002). The empirical focus of this work was the changes brought about by one dynamic and deeply internationalized industrial sector, semiconductors (Ernst, 2005), a sector that is increasingly located in Asia. This offered an excellent site to follow the increasing flow of capital (through FDI) and knowledge (people, R&D investments, firms' acquisitions) between the US and Asia. Ernst (2006) reviewed the scholarly literature necessary to support a concept of global innovation networks: Chandler, Dunning, Cantwell, Pavitt & Patel are there, informing the intellectual roots of the concept.

Ernst also quoted a report by The Economist Intelligence Unit (2004) *Scattering the seeds of innovation*: *the globalization of Research and Development,* as a key source. A later EIU (2007) report is very often cited as the first reference to GINs, although it did not cite Ernst's (2006) earlier

work (for instance OECD, 2008a). It suggests that centralized R&D is increasingly being replaced by 'global innovation networks'. It seems to integrate different processes that occur simultaneously – the internationalization of R&D, relationship between firms and other external sources of technology, and changes in the management of TNCs. This business journal provides short and objective reports that highlight what are identified as new facts or phases in the world of technology, in a language adapted to the world of consultants and business people. For researchers of technology, the approach of *The Economist* can be taken as an empirical sign of changes in the world of technology. The work of Ernst and The Economist are seminal texts for an emerging research literature.

I.1. GINs and the Literature on Internationalization of R&D

The internationalization of innovation activities and the interaction between firms and external sources of technology - now branded as "open innovation" (OECD 2008b) – are processes that have been evolving and on the agenda of the economics of technology for some time.

The literature on the transnational and international distribution of innovative activities may be divided into three phases. A first phase surveyed by Caves (1996) includes papers and investigations until the beginning of the 1990s, which stress the strong correlation between R&D intensity and multinationality.[1] Analysis of this literature found that while the percentage of R&D performed abroad had increased over the past two decades the prevailing tendency was still for research to remain based at the headquarters of TNCs. A second phase began in the 1990s, when the literature dealt with the increasing internationalization of transnationals' R&D activities. Examples of this line of research are OECD (1998) and special issues of *Cambridge Journal of Economics* (Technology and Innovation, February 1995) and of *Research Policy* (Internationalization of Industrial R&D, March 1999).[2]

In an early work, Dunning (1995) identified four circumstances in which MNEs would engage in foreign-based R&D: for product or process improvements, research into basic materials or products, efficiency-seeking research to acquire foreign technological assets or benefit from innovation activities. Decentralization of R&D is a process that is not so new, if one takes as reference the literature on transnational corporations. Kuemmerle (1997) investigated "global research networks", suggesting that qualitative changes take place in the course of this process. Kummerle (1997) suggested a distinction based on the direction of the technological flows. "Home base exploiting" foreign R&D flows to the foreign laboratory from the centralized R&D unit of the MNE, and "home base augmenting" foreign R&D flows to the central laboratory from foreign competitors and universities. Dunning (1995) speculated that such "home base augmenting" type of R&D would become more important over time and increase rapidly, attracted to countries with a more advanced technological and educational infrastructure.[3] Narin et al (1997) captured similar processes in their

[1] This finding is very important to articulate the nature of NSIs and the presence of headquarters of TNCs – especially in the periphery.

[2] For a review of the literature on the first and second phases, see Biazzi & Albuquerque (2002).

[3] According to UNCTAD (2005, p. 188), this asset-seeking FDI R&D-related creates more R&D linkages, establishing more connections with local universities.

investigation of flows between science and technology, citing the contribution of local and foreign competitors and universities to IBM's patented knowledge as an example.

What is really new, besides quantitative differences: probably the rise of Asia and other non-central regions (what UNCTAD calls developing and transition economies) and the role of talent pools as attractors of R&D-related FDI.[4]

The third phase is related to research on internationalization of R&D and the emergence of the concept of GINs (Ernst, 2006; *The Economist Intelligence Unit,* 2007; OECD, 2008a, 2008b).

Two reports from UNCTAD (2005, 2006) are examples of a transition between the second and third phases, since they deal with subjects that are typical of the third phase, but do not name them as 'global innovation networks'. UNCTAD (2005) showed how far the process of R&D internationalization had progressed, and highlighted the emergence of developing economies as locations for R&D.[5] It described the early stages of the rise of China as a location for foreign R&D, several examples of R&D international networks, such as Motorola or Toyota, and examples of R&D undertaken by subsidiaries of foreign affiliates in South Korea, Brazil, Morocco, Kenya and Czech Republic. While UNCTAD (2005) first reported the expansion of R&D abroad by developing countries TNCs, examining the cases of Chinese, Indian and Korean TNCs, UNCTAD (2006) evaluated the rise of TNCs from developing and transition economies.

I.2. GINs as a New Phase of Internationalization of Capital

Essentially, the contribution of this strand of the literature (Ernst, 2006; *The Economist Intelligence Unit*, 2007) is to identify a new phase in the history of global capital, of generalized changes that merit investigation.

These processes have been investigated by researchers investigating interconnected phenomena, sometimes using other terms, such as global industries (Macher & Mowery, 2008); international value chains (Linden et al, 2007); or internationalization of labor markets (Richard Freeman, 2007).

The conceptual elaboration of GINs has evolved. Ernst's (2009) later work dealt more critically and in a better informed way with issues such as the emergence and diffusion of GINs. GINs emerge as a natural expansion of Global Production Networks and share the three defining characteristics. A first common feature is "asymmetry" (Ernst & Naughton, 2008), given that the hierarchy between firms, countries and regions impacts on and is preserved within GINs. Global firms create GINs to take advantage of the rise of global markets for technology, in order to increase return on investment by penetrating high-growth emerging markets. One important clarification is the dominant role of leading firms – termed network flagships - in the formation of GINs and in determining the nature of networks.

[4] In two articles representative of the special issues of the *Cambridge Journal of Economics* and the *Research Policy*, Cantwell (1995) and Cantwell & Janne (1999) discuss only R&D located and relocated within developed countries. Taking Figure 2 as reference, this literature dealt only with the relationships between countries 1 and 2, at the capitalist center.

[5] UNCTAD (2005, p. 181) points to the connections between countries 1 and 3 in Figure 2.

Ernst (2009) thus argued that GINs can be a "mixed blessing", with negative effects on less developed countries. The global centers of excellence remain located in the United States, Japan and European Union, which are able to retain their dominant position and control over the "emerging new geography of knowledge". The new global hierarchy is characterized by a distinction between "global centers of excellence", "advanced locations", "catching-up locations" and "'new frontier' locations".

A second common feature of GINs and GPNs is that a variety of governance structures are found, ranging from loose linkages to highly formalised networks. And a third feature is that knowledge sharing is at the core of networks. The flagship firms in the network gain access to skills and capabilities but more significantly, they may access new ideas, models and processes.

An important contribution of this work is the development of a "taxonomy" of five types of GINs based on the analysis of Asian firms (Ernst 2009):

1. Intrafirm networks, in which TNCs 'offshore' stages of innovation to their Asian subsidiaries,[6] characterized typically by an inequality in the division of innovation tasks[7], for example, Texas Instruments, Cisco and Intel, with labs in Bangalore
2. Interfirm networks, in which TNCs 'outsource' stages of innovation to specialized Asian suppliers, for example, Hewlett-Packard, Dell, Acer and Lenovo use design services provided firms from Taiwan
3. Networks of Asian flagship companies, in which Asian firms develop their own networks, mostly intrafirm but increasingly, located in developed economies, for example Chinese Mobile, MediaTek Taiwan or Huawei
4. International public-corporate R&D consortia
5. Informal social networks of students and other knowledge workers

I.3. Disentangling the Concept of GINs

This literature intertwines diverse factors that operate in the present transition towards a new phase of capitalism. The emergence of GINs is related to a broader global context that may be characterized by academic discussions on the decline of US hegemony, as put forward by Arrighi (2007). Arrighi's view has been subjected to huge criticisms, and the discussion about his global diagnosis help to prepare an evaluation of the present challenges and changes (see the special issue of *Historical Materialism* on Arrighi's work on China). On the other hand, the investigation about GINs contributes to a better understanding of the changes under way.

What are the factors that integrate the elaboration on GINs?

[6] UNCTAD (2005, p. 104, Box III.2) defines three categories of internationalization of innovation. Its third category – "international generation of innovations" – would fit this "type" of Ernst's taxonomy. The UNCTAD's report is clear about the role of TNCs: "the TNC is the only institution that, by definition, can control and carry out within its boundaries the process of innovation across the globe" (p. 104).

[7] UNCTAD (2005, pp. 173-177).

First is a new stage in the nature of transnational corporations, those "dominant R&D players" (UNCTAD, 2005:119), as they are one key 'driver' of the emergence of GINs (Ernst, 2006; 2009). Dunning (2008) highlighted how TNCs reshape the international division of labor. One change is the emergence of TNCs with headquarters at the periphery (UNCTAD, 2006), which construct their own GINs as in type 3 GIN of Ernst's taxonomy (2009).

A second factor is the emergence of new technologies, the ICT revolution. It is noteworthy that the case study of Ernest's pioneering research is chip design (Ernst, 2006). Similarly, Linden et al (2007) research focuses on PCs, Apple, and iPods. The report on *Innovation in global industries* (Macher & Mowery, 2008) evaluates only high-technology sectors such as PCs, software, pharmaceuticals, biotechnology and flat panels. The ICT revolution enhances the mobility of innovation (Ernst, 2006).

Third is the emergence of Asia as an economic power and new destination for foreign R&D, especially China, and India (*The Economist Intelligence Unit* 2007). This rise of East Asia has potential implications that have been explored by Arrighi (2007). In an important book on China, Naughton (2007) identified a process of deeper integration into global production networks that includes R&D outsourcing and internationalization of innovation as a source of opportunities. Through a case study of Lenovo's outsourcing of its laptops and PDAs, Naughton raised the question whether these initiatives could turn the international model of subcontracting around. Therefore, the issue is not only the emergence of Asia, but the risk of broader hierarchical changes in the global economy. Beyond Asia, the emergence of other locations like Brazil, South Africa or Mexico are a specific characteristic of this new phase.

Fourth, are changes in the relationship between firms and other sources of innovation, or the trend towards "open innovation" (OECD (2008b) OECD (2008b. This is an old subject of the literature of innovation and important for the understanding of the international movements of TNCs. There is an intensification of what has been an important feature of innovation - that firms do not innovate alone - which becomes more visible when the arena is the world.

Fifth, globalization is sometimes understood as the liberalization of capital flows throughout the world or as a process driven by liberalization. Ernst (2006) stressed that liberalization been a catalyst for the expansion of global production and innovation networks. This is a naïve view of the globalization process, that has determinants that goes beyond strictly economic factors: Wood (2003, pp. 137-142) has highlighted the role of states (especially the state of the United States) for this phase of "internationalization of market imperatives". According to Wood (p. 139), the state "has created the conditions enabling global capital to survive and to navigate the world" (see also Panitch & Gindin, 2005).

A sixth factor that is intertwined with the emergence of GINs is changes in the international division of labor – an old process, pushed by international movements of capital (for a broader view, see Silver, 2003). The relocation of capital, of manufacturing and of R&D activities have been investigated in the literature on the internationalization of R&D and GINs. There is also an increasing division of labor in innovation (Ernst, 2009) that in turn, is another driver of GINs. These changes in the international division of labor have highlighted concern about the future of the hierarchy within

the international division of labor. However, although this point is not very much emphasized in the literature, there are those who argue that the repositioning of labor internationally may not subvert the existing hierarchy (Ernst, 2006,; Macher & Mowery, 2008; Jefferson, 2007).[8]

Seventh, are the educational consequences of the processes of formation of national systems of innovation at the periphery. The engineering and scientific resources available in countries like China and India opens new options for TNCs – to hire specialized people with lower wages (Freeman, 2005; see also Ernst, 2006). This seems to be the real novelty of by the GINs approach, particularly the new location of this talent pool. In the case of China, Sun (2002) and Spence (1990) stressed the role of one of the "four modernizations" defined by Deng Xiao Ping, in the late 1970s: science and technology as a "productive force", and the plan to train 800,000 "scientific workers" (Spence, 1990: 611).

To disentangle these seven different factors in order to understand the nature of GINs is a theoretical challenge, necessary to deal with our specific topic – interactions in a global context.

II. INTERACTION WITH UNIVERSITIES AND GINS

The paper began by postulating that although the two strands of literature of innovation - on interaction and on GINs - both mention universities and foreign corporations, neither conceptualises the two concepts together in a systematic manner as core research focus.

On the one hand, Klevorick et al (1995) and Cohen et al (2002) investigate firms interacting with universities. Some of these firms may be headquarters of TNCs, for instance, an investigation of IBM and its knowledge flows (Narin et al 1997). In general, however, this literature tends to investigate interaction within a single country and limited by national boundaries.

On the other hand, universities are typically seen as important for the emergence of GINs, but there is little direct focus in the research on their role. The literature on GINS points to the role of the talent pool available in peripheral countries as one key driver of GINs (Ernst, 2006; *The Economist Intelligence Unit*, 2007). It may consider the importance of universities for GINs, and the entanglement between GINs and "open innovation", for which universities and research institutes are important external sources of knowledge, but not as a core focus of investigation.

This section thus evaluates how each strand of the literature on innovation deals with the issue that is not at its core – how the literature on firm interaction with universities deals with the globalization of R&D, and how the literature on GINs deals with the role of universities. It then investigates how universities and firms shape their relationship through earlier stages of development – a key connection between science at the center and universities at the periphery.

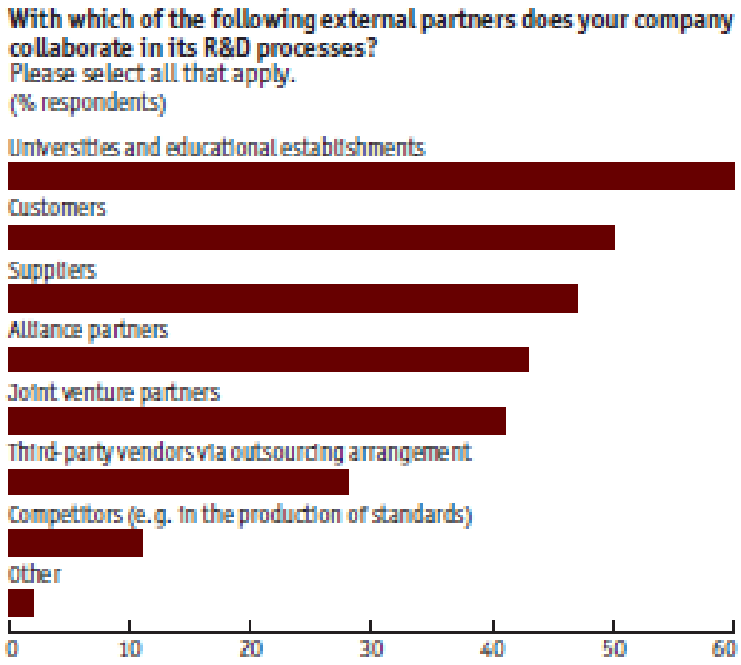
[8] Jefferson suggests that the movements related to GPNs and GINs only reshape the international division of labor while preserving the technological hierarchies. According to him, "[j]ust as the phenomenon of FDI and R&D offshoring leads to spillovers that induce Chinese firms to establish rudimentary operations, the same pattern of offshoring is also motivating the United States and other OECD MNEs to upgrade and diversify their R&D operations in order to maintain control the development and deployment of critical technologies" (Jefferson, 2007, p. 213)

II.1. References to Universities in the GINs' Literature

The literature on GINs definitely displays awareness of the significant relationship between GINs and universities and research institutes, but this is typically implicit and largely unexplored.

In the earliest literature, elaboration of the external partners that collaborate with global companies in their R&D processes included universities alongside customers, suppliers, alliance partners, joint-venture partners and so on. Kummerle (1997) pointed to foreign universities as targets for "home base augmenting" foreign R&D. A survey of 300 executives (*The Economist Intelligence Unit,* 2007) highlighted the significance of universities and educational establishments, which were reported as the most frequent collaboration partners, for 60% of respondents (Figure 1).

FIGURE 1
GINs and External Partners



Source: *The Economist Intelligence Unit* (2007, p. 10)

Likewise, an OECD (2008b) report aimed to show how the use of external sources of technology is increasing and goes hand-in-hand with global innovation networks. Universities and research institutes are identified as critical sources of innovation, so that there is a growing trend towards the globalization of industry-science relationships. One mechanism was the establishment of units to identify potentially interesting R&D at universities. Another was new financial arrangements, c*orporate venture capital* divisions (Gompers & Lerner, 2001), to access new ideas through joint ventures, acquisitions or university-based collaborations. Thus, at least three out of six reasons for major companies to invest in R&D in China were related to universities – the pool of talent available,

the pursuit of private funding sources by universities and research institutes, and the possibilities of accessing new innovations and entering into IPR agreements (UNCTAD, 2005).

The shift from in-house, centralized R&D units towards such strategic alliances with other firms or universities is stronger in certain sectors such as pharmaceuticals, given that a single company cannot have expertise in all the research areas required for developing new products (UNCTAD 2005). The literature is replete with examples from other sectors, taking different forms. Examples of collaboration between foreign affiliates and local universities range from Microsoft Asia in partnerships with Chinese universities, Intel which reports 250 sponsored research projects and STMicroeletronics which has a training center in Rabat, Morocco (UNCTAD 2005).

Examples of Asian firms that have established GINs with amongst others, universities in the USA and Europe include China's Huawei (Ernst& Naughton, 2008) and Taiwan's TSCM (Ernst, 2009). Type three of Ernst's (2009) taxonomy specifically mentions universities only with regard to these Asian firms GINs. Of course, in the two first types (intrafirm and interfirm), the direct and/or indirect links with universities are implicit, given the previous formulations of Dunning (1995) and Kummerle (1997) incorporated in Ernst's elaboration. Ernst's type four GIN, international public/corporate R&D consortia is not well elaborated or exemplified, but it has strong parallels with the category of "internationalization of innovation" that involves universities, public research centers, national firms and TNCs (UNCTAD, 2005). It is not difficult to identify actual examples, such as EUCAGEN (Eucalyptus Genome Research), involving 82 public and private institutions, including a Brazilian firm, Fibria (Penchel, 2008).

This literature thus emphasizes the significance of universities and public research institutes in the formation of different types of GIN, but in a peripheral way. It focuses on firm strategies and does not elaborate on the nature of interaction or the role of universities in national systems of innovation in any depth.

II.2. References to International Networks in the Literature on Interaction

In contrast, Ernst (2002) has highlighted the change towards decentralization of R&D in the last decades, and criticized the literature on the national system of innovation for a neglect of the international dimension. This is a very strong criticism. Other papers on the internationalization of national systems of innovation recognise the limited focus of this literature beyond national boundaries (Carlsson, 2006). The international dimension is part of the elaboration of national systems of innovation, even if authors related to the evolutionary approach emphasize the relative slower trend towards the globalization of technology, vis-à-vis finance and production (Cantwell, 1995; Patel, 1995).

But, if we look closer and go beyond the more popular side of evolutionary papers, we can find important clues to the relevance of the international dimension – at least implicitly. Science is international, by definition (Zitt et al, 2004). A key subject investigated by the evolutionary approach – catch up processes – highlights the importance of international contacts and access to foreign knowledge. Every description of a successful catch up process necessarily deals with flows of foreign

technology and science. One very simple suggestion would be to re-read Nelson's book on national systems of innovation (1993) and take notes about how each emerging country – when it was emerging to take technological leadership – designed creative ways to access and use knowledge available elsewhere: Germany learned from the UK; the US learned from Germany; Japan learned from Germany, England and US; Korea learned from Japan and the US. Students sent abroad, engineers invited to create faculties, foreign engineers hired to run new firms, factories bought, visits to top firms and top universities: various different ways were designed to absorb knowledge available elsewhere.

Other research suggests that changes in the international scenario impacts the fate of (important) NSIs, as the case of the US after post-war European and Japanese catch up suggests (see Nelson & Wright 1992). TNCs matter (Chesnais, 1988, 1994). Studies of international alliances and cooperation show how connections between different NSIs are established (Hagedoorn, 2002; Ostry & Nelson, 1995).

Scientific infrastructure may be an important attractor of foreign firms (Pavitt, 1991). In an investigation of the levels of and changes in foreign R&D of US TNCs, Patel (1995) found that the firms that most internationalized their R&D were in the beverage and tobacco, food, building materials, other transport, pharmaceuticals, and mining and petroleum sectors. These are not sectors typically characterized as high technology, nor are they typically associated with a global mandate as are computers or automotive sectors (except for pharmaceuticals). Most of the R&D activities related to localized adaptation to take into account differences in consumer tastes and government regulations or to exploit local natural resources. Patel proposed that the firms with higher R&D intensity were internationalizing technological activity to a lesser extent, because production and R&D were required to be in close proximity to one another.

Patel's research is a useful identification of changes over time. Since 1995, as Ernst has suggested, there has been a rise of internationalization of high-tech sectors. Furthermore, Patel pointed to specific reasons that lead to the internationalization of R&D in sectors like food, mining and petroleum that are still operating currently. As time goes by, the nature of foreign R&D activities becomes more complex.

The lack of focus on the international dimension of national systems of innovation is thus not inherent to the approach, and is conceptually possible.

II.3. The Changing Role of Universities at the Periphery[9]

The nature of technological progress in capitalism was discussed by Marx (1867), showing how a permanent revolution of the technological base is a key factor of capitalism. Later, Schumpeter (1939), Mandel (1974) and Freeman (1982) have shown how through long waves of capitalist development, technological revolutions shape and reshape the structures of the capitalist economy. The literature on interaction between science and technology in developed countries could be read as

[9] This sub-section is based on Suzigan et al (2009).

explaining how these technological revolutions are generated from the center. The technological revolutions generated at the center of capitalism are diffused throughout the whole world and impact on the countries at the periphery of the capitalist system (Furtado, 1986). Therefore, the structuralist polarity between center and periphery, suggested by Prebisch, is one important starting point for our theoretical background (see Furtado, 1986).

This illuminates the standpoint from which we investigate the interaction between universities and firms: at the periphery, a part of the world where technological progress generated at the center impacts and determines the position of countries in the international division of labor.[10] The impacts of the waves of capitalist development change and reshape the challenges and opportunities for catching up. This dynamic international technological framework is the context in which universities at the periphery establish their first role: universities might be an important channel to absorb knowledge generated abroad from the center of technological dynamics. It implies that the tasks of universities and firms related to knowledge absorption are ever changing.

Universities and PRIs are one of the first channels to connect a country at the periphery to the international flows of science and technology.[11] Their first universities and PRIs were created with foreign teachers and/or local students that graduated abroad.

Late development, by definition, means high levels of poverty, inequality, strong social problems such as ethnic segregation, and colonization. Therefore, since their formation, local universities and PRIs are confronted with great challenges, which determine a "dual role" for them. They must, on the one hand, keep in touch with scientific and technological development at the center while, on the other hand, they will face local problems and issues (diseases, soils, plant varieties, geological conditions) that need specific investigation and might generate new scientific knowledge.

Furthermore, there are various tasks to be performed by universities/PRIs: teaching, training of human resources to populate public administration (specially at the beginning of the nation building process) and to create the first firms (sometimes part of them state-owned: infrastructure, key mining and manufacturing sectors), diverse problem solving tasks and eventually (in the beginning) truly original scientific research (specially in agriculture and health).

Later, during the initial industrialization process of late comers, a kind of wave of institutional formation seems to be an empirical regularity, with new PRIs and universities (or at least faculties) that may help to solve new and more complex problems. The process of university formation is multifarious, therefore neither determinist nor automatic. There may be demands to solve societal needs (to fight diseases and epidemics), there may be demands from organized agricultural producers to face plagues or bugs that harm harvests, from mining sectors to up-grade mining techniques, there may be demands from governments to provide tests for infrastructure building. There also may be institutional building ahead of demand that later should foster the creation of new industrial sectors and/or provide engineers to work in transnational corporations moving to that country.

No matter what the driving force for institutional building, once created universities and PRIs trigger a new process that has new actors, with new demands and opening new opportunities for the

[10] For an attempt to articulate the process of technological revolutions at the center and its impacts on a peripheral country like Brazil over time, see Albuquerque (2007, section 2.2).

[11] Other forms of early connections to developed countries are travelers, traders, and study abroad.

local economy and society. One important feature of this new dynamic is the attempt to preserve links with the evolving S&T international environment.

The growth of universities and PRIs and consequent diversification is itself a process with social resistance and not easy. Size, diversity and quality of universities depend upon social variables like the reduction of illiteracy, universal access to basic and secondary schools, which are dependent upon other social variables such as income distribution and welfare conditions. Social constraints to university development create limitations in the role of universities for development.

As universities and PRIs grow, their dual role becomes more complex. On the one hand, they must perform their role as "antenna" for local society and economy in a broader range of S&E fields, since these fields grow in number and scientific complexity at the center. On the other hand, local demands and local research questions grow in size and complexity. This role as "antenna" changes over time, with new tasks put forward by technological revolutions at the center. This role exists throughout all development phases: compare the role of National Agricultural Research Systems (NARS) to diffuse GRMV (Evenson, 2003) and the creation of the Korean Institute for Electronic Technology (KIET), in South Korea (Kim, 1997, p. 214) to help local large firms to enter the computer and semiconductors industries.

The diversity of forms of interactions between universities and firms may be further illustrated by the Chinese experience: as Eun (2005) has shown, academic-run enterprises and university-run enterprises are specific forms of relationship. Eun et al (2006) suggest that these modes of interaction are specific for a context of universities with stronger capabilities than firms. Financial conditions matter here, since universities have access to state and to township and village resources that may fund new firms that they create - but they do not spin-off. This Chinese specificity, as Eun (2005) explains, has historical roots that can be traced back to 1949, the foundation of PRC. Eun mentions "three major peaks of academic-run enterprise development", during the Great Leap Forward, during the Cultural Revolution and after Deng's reforms (especially the S&T reforms). Lenovo, one of the Asian GINs studied by Ernst (2009), was created as university-run enterprise, showing how a firm spun-off from a local university (therefore, already plugged into a network of knowledge) then becomes independent of that local university and finally establishes interactions directly with other universities abroad.

In sum, over time the evolution of local universities means that their roles become more diverse (teaching in new areas, research in various directions, following diverse motivations, demands for advice for public policy and public health) - or what Eun et al (2006) call the universities capabilities develop.

III. A TENTATIVE SYNTHESIS: GLOBAL INTERACTIONS BETWEEN FIRMS AND UNIVERSITIES

The review of the literature in section II provides a picture of the current phase of internationalization of capital. This is a process whose drivers have been explored since the investigations in the classics of political economy (Adam Smith, David Ricardo, John Stuart Mill and Karl Marx) of the push towards new regions and sectors to escape the curse of falling profits.

Grossmann (1929) presents a broad overview of the mechanisms operating to counteract the falling rate of profit, and pinpoints the export of capital as one key mechanism. Exports of capital have carriers – the transnational corporations. There is a history of these movements (Dunning 1995) that over time grow in size and complexity. In 1857-1858, Marx had uncovered the complex and indispensable relationship between capital and science – it is possible to speculate that the international movements of capital may not happen alone, since they need science to operate. Marx wrote the *Grundrisse* and *Capital* in a time when the "technological application of science" was in a pre-historical period – the research on GINs and interactions points what is necessary for today's capital movements across national borders.

Steindl (1976) in the revision of his stagnationist view of post war capitalism points to the underestimation of international flows of capital as an alternative channel for over-accumulation at the United States. Ellen Wood (2003) provides a good review of the classical literature on capital's push towards new regions: she highlights a new phase since the crisis of Bretton Woods, suggesting that "globalization" was an answer to problems at the center of capitalism, based on the analysis of Robert Brenner (2006) about the long downturn of US capitalism.

The classics of political economy and authors working on topics related to contemporary political economy may inform an adequate framework for research to deal with this new phenomenon of global capital. In particular, this framework would help to understand how hierarchies are preserved and renewed under new conditions in this process. The acceleration of technical change (a new feature of the last long wave of capitalist development[12]) has pushed changes in the architecture of national systems of innovation, with a more complex institutional division of labor between its institutions. OECD.

The arguments presented in this paper suggest that GINs have not one, but two main drivers. First, is the TNCs and their growing capabilities, technological and locational diversity, as they move across the world selecting locations and distributing productive and innovative labor. Second, the formation and improvement of national systems of innovation, especially at the periphery, is a process that goes far beyond the limited push of capital towards new regions and sectors. One important engine of this process is the internationalization of science. The formation of NSIs involves political forces that shape states and their autonomy, capabilities and public resources to generate and support their public institutions. For example, the rise of talent pools is a consequence of investments in science and engineering that shape NSIs.

Therefore, there are two movements reshaping and reorganizing the international division of labor. This reshaping of the international division of labor, in turn, affects the internal decisions of TNCs and the actions of their subsidiaries, pushing further changes in the international division of innovative labor.

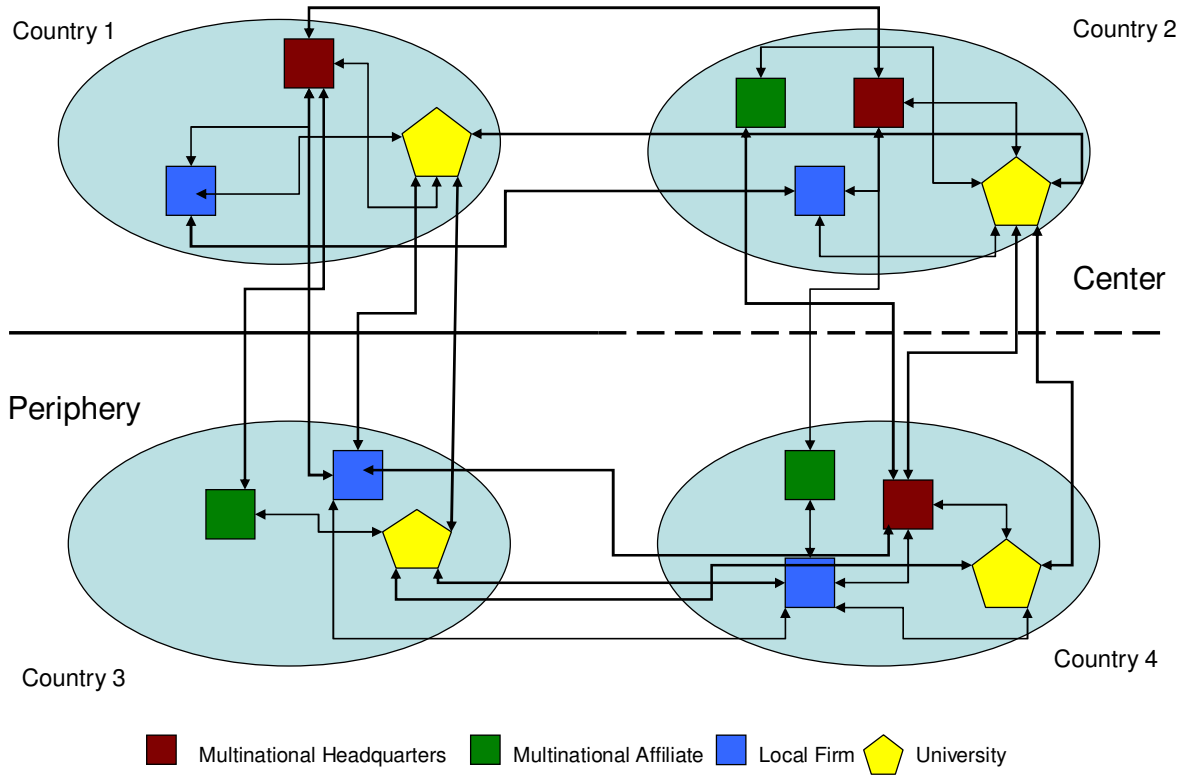
The combination of these two drivers leads to a complex picture, where the nature of NSIs matters for the formation of networks, their main characteristics and the nature and scope of the international hierarchies established, which is the subject of the concluding section of this paper.

A tentative framework to is suggested in Figure 2. Firms - local and TNCs - universities and their links, are reflected in a hierarchical world, divided between a center and a periphery (Furtado,

[12] This is well captured by Mandel's *Late Capitalism*, in the early 1970s.

1982), and the implicit social and political forces that shape NSIs defining the major countries' characteristics and possibilities within a global innovation system in the making.

FIGURA 2
Global Interactions between Firms and Universities - A Tentative Framework



Source: authors' elaboration, following a review of the literature (see section III).

Figure 2 reflects a division between center and periphery. But this divide has two features: the first is portrayed as a continuous line, the other as a discontinuous line. The difference is intended to express graphically the possibility of catch up – the emergence of a country that successfully overcomes underdevelopment. The case of South Korea during the 1980s and 1990s is a case in point, the inescapable goal of all serious technological policies.

The tentative framework suggested in Figure 2 was not created out of the blue. It is based on the literature discussed in the previous sections. The main contributions that underpin the logic of Figure 2 are summarized and reiterated here.

The starting point is work that conceptualizes the interactions between firms and universities in developed countries, based on interactions within a single country (Klevorick et al 1995, Cohen et al 2002). These are reflected in Country 1 in Figure 2. This work has been elaborated to examine the interactions between firms and universities in developing countries, again, interaction within national

boundaries, but which may include TNCs's subsidiaries in those countries (Rapini et al, 2009, Lee et al, 2009, Kruss, 2009). These are reflected in Country 3 in Figure 2.

A similar limited set of interactions are suggested by Patel and Pavitt (1998), who are very cautious on the internationalization of innovation. They stressed the ways in which firms in developed countries may use other countries' scientific infrastructure as sources of information, where national systems are not able to meet the needs of innovating firms. These are represented as interactions between TNCs in country 2 and universities in country 1 or vice versa.

A critical work that links the two strands is the UNCTAD (2005) study that demonstrates the chain of TNC connections between developed and developing countries, linking countries 1 and 3 in Figure 2. Ernst's (2009) taxonomy of GINs, specifically types 1 and 2, further informs the elaboration of these links (between countries 1 and 3).

However, Ernst's (2009) elaboration of a type 3 GIN, of a TNC based in a country at the periphery and interacting with universities at the center, has informed the elaboration of the framework. This is reflected as the connections between a TNC with headquarters in country 3 or 4 and its subsidiaries in country 2 and universities in country 1 or 2. Likewise, Azevedo (2009) analyses a transnational firm based in a peripheral country that has research collaboration with 70 universities and research centers abroad (a firm from country 3 interacting with universities in countries 1 and 2 – or multiple countries at the center).

OECD (2008b) research on Japanese TNCs and their networks with universities in China, India, Japan, and the US illustrates a different set of possible connections between TNC headquarters, TNC subsidiaries (including in the US) and universities. These are reflected as connections between country 1 and 2 and between country 1 and country 3 and/or 4 in Figure 2.

The literature also highlights a growing trend towards connections between firms based in different countries at the periphery, for instance, biotechnology inter-firm networks (Thorsteinsdóttir 2010). Those firms were typically born as spin-offs of local university research, with its international connections. These are represented as connections between local firms in country 3 and local firms in country 4.

The significance of connections between the universities – the science networks – is also included in the framework. There are strong "engines of internationalization" of science, old and new (Zitt et al 2004).[13] For developing and catch up countries, the networks of science and related educational investments may be the first networks to be established, to connect one country with the global knowledge networks centered in the leading countries. Examples are global research consortia such as the *International Human Genome Sequencing Consortium*, with research institutes from the US, China, France, Germany, Japan participating. It is important not to underestimate these scientific

[13] The engines of science internationalization are, according to Zitt et al (2004): 1) "History of science teaches that scientists consider it natural and profitable to freely communicate and collaborate, and professionalisation of science in the XIXth and XXth centuries has fostered this trend. This self-organisation is the first engine of science inernationalisation" (p. 408). 2) "multinational programmes" common after the WWII – "top down processes and self-organisation interact in many ways in large scale programs" (pp. 408-409); 3) "general movements of financial and economic globalization" – "R&D services' implementation and their articulation with local research are often viewed as an important internationalization engine"; 4) the ICT revolution and the explosion of electronic networks have "boosted non-physical exchanges and especially scientific work" (p. 409).

networks, as discussed in sub-section II.3. These scientific networks connect all four countries in Figure 2.

Supported by this literature, Figure 2 is a starting point for a tentative framework to deal with global interactions between firms and universities. This framework would yield seven main types of interactions, which necessarily go beyond GINs, both backwards and forwards:

1. only local interactions
2. international interactions of local firms
3. transnationals interacting only with home country universities
4. transnationals interacting both with home country and host country universities
5. a type that may mix characteristics from the four types above
6. a non-hierarchical network between TNCs headquarters and subsidiaries and their connections with universities
7. international consortia between firms and universities.

These seven types are elaborated in the following paragraphs.

TYPE 1 – ONLY LOCAL INTERACTIONS. These are interactions between local firms and local universities. This type does not involve cross-border transfer of knowledge. It could represent the first step for a firm to become transnational. That is, it allows for an initial accumulation of knowledge and capabilities that supports a transition from being a local to a transnational firm, since there is a deep correlation between transnationality and R&D-intensity (Caves, 1996). In Figure 2, these are represented as the relationships between firms and universities within each country. In earlier stages of capitalism at the center, they could be the typical and most advanced interactions with universities. Now, this type of interaction may be located in firms at the periphery – within countries 3 and 4.

TYPE 2 – INTERNATIONAL INTERACTIONS OF LOCAL FIRMS. These are interactions between local firms and foreign universities. This is the first and simplest form of cross-border transfer of knowledge. In Figure 2, this flow would connect a local firm in country 1 and a university in country 2. This type would normally overlap with type 1, since local firms would typically interact both with universities in their home countries and with foreign universities. Historically, this type would have first connected developed countries (countries 1 and 2). Currently, this type of interaction would be important for local firms at the periphery looking for knowledge that the local science infrastructure would not be able to provide. In Figure 2, this is represented as a connection between a local firm in country 3 and a university in country 1.

TYPE 3: TRANSNATIONALS INTERACTING ONLY WITH HOME COUNTRY UNIVERSITIES. This would be the typical relationship reported in the literature on internationalization of R&D. The TNCs have connections with their home country universities, but the host countries either do not have R&D activities or the R&D activities are completely centralized at the TNC headquarters.

TYPE 4: TRANSNATIONALS INTERACTING BOTH WITH HOME COUNTRY AND HOST COUNTRY UNIVERSITIES. This would be the more recent pattern of interaction. There is a broader division of innovative labor within the TNC, with the possibility that a subsidiary assumes contacts and performs contracts with the host country university. The nature of this relationship will depend on the nature of the subsidiary's role within the TNC, ranging from limited adaptive activities – that would require contacts with local laboratories or engineering departments – to more advanced projects – that would involve R&D joint research with local universities, sometimes in connection with foreign universities too. The hierarchy and the decision-making about the specific roles of home-country and host countries R&D departments may vary deeply, and this variety should be incorporated within this type.

TYPE 5: FIRMS THAT INTERACT WITH NETWORKS OF UNIVERSITIES. Firms (local or transnational) may establish contact with one specific university (local or foreign) but would take advantage of the other universities (local or foreign) that are linked to the first university through their existing scientific and educational links. This is important, given the natural trend to the internationalization of science, with its formal and informal links. The interactions of firms with networks already established among universities are rich in multidirectional knowledge flows.

TYPE 6: A NON-HIERARCHICAL NETWORK BETWEEN TNC HEADQUARTERS AND SUBSIDIARIES AND THEIR CONNECTIONS WITH UNIVERSITIES. This type is non-existent, since asymmetry and hierarchy are "defining characteristics of both previous GPNs and existing GINs (Ernst, 2009). But this type must be included to benchmark to prevailing international networks. This type could be seen as a desired feature of a global innovation system.

TYPE 7: INTERNATIONAL CONSORTIA BETWEEN FIRMS AND UNIVERSITIES. This type involves firms, universities and research institutions, but they might be proposed and coordinated by the academic side of the interaction. Intergovernmental cooperation and international institutions, such as WHO, could trigger this kind of interaction. They could be "mission-oriented" and necessarily non-hierarchical. They also could be a characteristic of a global innovation system.

These seven types elaborated on the basis of the framework attempt to summarize the full range of interactions, but they certainly do not cover all possibilities. Many real world cases would be mixed cases. For example, the formation of international networks that may combine interactions at TNC headquarters that have interfirm connections with local firms in a foreign country, and this local firm may have interactions with local universities. Another example is a TNC that establishes contacts with foreign universities either in countries where it does not have a subsidiary or directly with a foreign university, bypassing its local subsidiary.

There are two differences with Ernst's taxonomy that deserve comment.

First, the taxonomy elaborated here does not differentiate the home country of a TNC. A TNC with headquarters in peripheral country 4 and a subsidiary in country 2, with connections both with local and foreign universities is a type 4 interaction, equivalent to a TNC with headquarters in country 1 at the centre and a subsidiary in country 3. Over time, what changes is the appearance of TNCs based in peripheral countries (UNCTAD 2006).

Second, this taxonomy does not include a type of relationship that includes informal contacts – Ernst's "informal social networks". On the one hand, according to the literature on interactions, informal contacts constitute one very important source of information even in developed countries (Cohen et al, 2002). On the other hand, students sent abroad, brain drain and brain gain movements are part of the dynamics of internationalization of science that could be described in Figure 2 as direct contacts between universities from the four countries. Since this taxonomy is designed to describe global interactions between firms and universities, these movements within the scientific networks are not defined as a separate type. However, as discussed in previous sections, these movements with the scientific networks are very important to the constitution of the global interactions discussed here. In fact, they are an essential precondition, it must be emphasized.

All of the changes in globalization of interactions discussed in previous sections can be evaluated using this taxonomy, which is necessarily static. However, it needs to be further elaborated to deal with a deeply dynamic environment.

TNCs from developing countries are a new phenomenon. Therefore, if Figure 2 were drawn to represent dynamics in the early 1950s, the arrow connecting a TNC headquarter in country 4 and its subsidiary in country 2 would not exist. Furthermore, the discontinuous line between the center and the periphery, between countries 2 and 4, opens up the possibility for catching up processes and for the overcoming of underdevelopment.

Another important dynamic feature is pointed to by the literature on networks (and may be captured by case studies). That is, "networks and innovation constitute a virtuous cycle" (Powell & Grodal 2005: 67). The knowledge exchanges and trust built during collaborative work and the achievements of the network, means that over time, networks may become less hierarchical. In sum, these network improvements over time must be incorporated in the taxonomy.

Finally, the taxonomy includes the empirical regularities unveiled by the literature on interactions (Cohen et al, 2002) and transnationals (Dunning, 1995) regarding sectoral specificities.

The integration between the literatures on GINs and on interactions between firms and universities, and the resulting framework on global interactions between firms and universities has an important theoretical consequence: the subject of the interdependence between national systems of innovation is clearly on the agenda.

IV. INTERACTIONS, NSIS AND TNCS: IMPLICATIONS FOR THE PERIPHERY

The framework presented in section III shows a connection between different NSIs – each country represents one NSI. From this standpoint, there is a direct relationship between the country's position in the international division of labor and the nature of their NSI.

There is a hierarchy in this international division of labor, as the strucutralist tradition has put forward with the elaboration on the center-periphery divide (Furtado, 1982). This divide has become more complex and nuanced over time, a consequence of industrialization processes (Amsden, 2001),

formation of NSIs at the periphery (UNIDO, 2005), and successful catch up processes (Amsden, 1989; Wade, 1990).

Using statistics of science and technology, Ribeiro et al (2006) divided the world into three different "regimes", and the periphery is divided between two of these.[14]

The maturation of NSIs may change the hierarchy of countries, and reorganize the international division of labor. But changes in the global hierarchy of NSIs are not easy. There are changes that only reinforce the nature of the dependency processes, with a modernization of the dependency structures (Furtado, 1982). Upgrading of industrial structures through the impact of technological revolutions at the center may only reshape existing structural problems in less-developed countries: there is a polarity of "modernization-marginalization" that is typical of underdevelopment (Albuquerque, 2007).

The changing nature of the center-periphery divide (Ribeiro et al, 2006) may be characterised by a "Red Queen Effect": countries at the periphery may run fast just to preserve their position in the international hierarchy of countries. Seen from the center, policies to sustain technological leadership are necessary (Macher & Mowery, 2008; Ernst, 2009).

There are global elements in (national) systems of innovation: at least one factor among the starting points of each national system of innovation is international. The taxonomy presented in section III highlights multifarious flows and links that create interdependence between NSIs.

However, participation within GINs depends both on the actions of TNCs and on the structural characteristics of the country shaped by its NSI. In other words, there are educational, industrial, scientific, public policies preconditions to join GINs, dependent on previous investments in the formation of its NSI.

On the one hand, the industrial landscape of a country is determined by the capabilities of its domestic firms and of its home-based TNCs. On the other hand, the quality of its country scientific infrastructure will define the kind of assets that a TNCs may seek within its borders.

Ernst`s (2009) evaluation of the role of asymmetry and hierarchy within both intrafirm and interfirm GINs suggests that one way to escape subordinate roles in GINs hierarchies is to own the flagship corporation that shapes the international network – as is increasingly evident (UNCTAD 2010). Therefore, formation of home-based transnational corporations is one key policy objective (Ernst & Naughton, 2008). Furthermore, BRIC's countries acquisitions of foreign firms are increasing as another strategy (UNCTAD, 2010). In the formation of home-based TNCs, peripheral countries have challenges and opportunities. Public policies need, to combine the old process of NSI formation and improvement with new challenges and opportunities opened by GINs and current changes in the world.

The TNC core sector depends on the strengths and specializations of each country's NSI. A list of top 100 non-financial developing and transition economies TNCs[15] shows this correlation with

[14] In this division, Korea and Taiwan are in the group of leading countries – both countries have joined this group in 1998, according to Ribeiro et al (2006), leaving an intermediate level populated by countries as Brazil, South Africa, Mexico, India and China. Therefore, there is a difference between Ribeiro et al (2006) and UNCTAD (2006), since for UNCTAD Korea and Taiwan still are "developing economies".

its home base specialization. Brazil has three TNCs in this list, related to its strengths in mining, petroleum and steel. Taiwan, with fourteen companies in the list, has nine in the "electric and electronic sector". Korea, with five companies, has two in the "electric and electronic sector". In sum: the NSIs position within the international division of labor also determines the nature of the country's TNCs, which, in turn, shapes one important feature of the country's involvement in GINs.

The theoretical framework presented in section III, particularly the proposition that both TNCs and the processes of NSI formation shape GINs, has one important implication for peripheral countries: the nature of NSIs shapes the national role in existing GINs. Therefore, immature NSIs will have immature (or incomplete) GINs – the limits of the NSIs will be reflected in sectors and nature of these GINs.

This leads to one simple conclusion – investment in the formation of NSIs is crucial as a guarantee of a less subordinate role in an emerging global system of innovation. This process of formation and improvement, with growing global connections and interactions, is a precondition for a more equal world, where the overcoming of the center-periphery divide is a real global goal.

[15] See http://www.unctad.org/sections/dite_dir/docs/wir2010_anxtab27.xls.

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